ADRE® for Windows® system detects an unbalance problem on an IP turbine rotor

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Making a conclusive and comprehensive diagnosis on a machinery problem can be difficult, expensive, and very frustrating without sufficient data and information. As this article shows, proper transducers (including type, quantity, and location) are imperative, particularly when you need to differentiate between the *source* of a problem and its *effects* or *symptoms*. Information provided by the right transducers provides a clear understanding of machinery behavior that often leads to better management and optimization of the asset, avoidance of costly maintenance, and safe, efficient operation of the machinery. The Sucat Thermal Power Plant in the Philippines provides such an example by contrasting the difference in data quality and results available both before and after proper transducers were installed.

Machine history

The Sucat Thermal Power Plant is one of the largest oil-fired steam turbine plants in the Philippines and is operated by the government-owned National Power Corporation. The plant was built in 1968 and has a total power generating capacity of 850 MW from four turbine generator sets (Table 1).

These turbine generators underwent extensive rehabilitation in early 1990 and are expected to generate full capacity for the next 12 years.

In September 1990, Sucat 4 was successfully rehabilitated and restored to full capacity (300 MW), with rated steam pressure at 186 bars (2,700 psig) at 538° C (1000° F). The boiler is a Benson, once-through type manufactured by Hitachi, while the turbine is a Siemens tandem-compound reheat type. The unit was initially fitted with a single eddy current proximity probe at (or near) each of bearings 1, 2, 3, 5, and 6. These bearing housings, as well as bearings 7, 8, and 9, were also each fitted with a single case-mounted seismic transducer.

Unit	Rating
1	150 MW
2	200 MW
3	200 MW
4	300 MW

Table 1. Rated output of Sucat generating units.

Unfortunately, the unit experienced a number of problems following this rehabilitation, and rapid diagnosis of many of these problems was hampered by a lack of proper transducers. Figure 1 shows a machine train diagram on Sucat 4, along with the sequence of vibration transducers added during the period covered by this article.

Sequence of events

On 16 April 1992, nearly 19 months

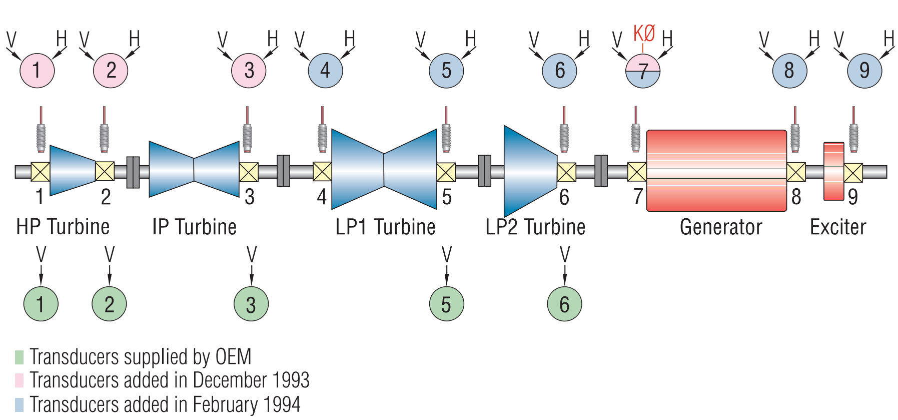

Figure 1. Sucat Unit 4 machine train diagram showing progression of transducer additions.

after rehabilitation, 11 panels of secondary superheater tubes broke. The integrity and reliability of the secondary superheater tubes came into question when the investigation revealed extensive damage. Plant maintenance personnel made temporary repairs on the damaged tubes and restored the unit to operation with a derated load of 250 MW and a corresponding decrease in the steam pressure to 159 bars (2,300 psig).

On 2 October 1992, six months after the repairs, a series of forced outages occurred because of leaks on the HP turbine leak-off pipeline. Each outage occurred shortly after each repair. A decision was made to replace the entire pipeline with stronger material during an outage on the unit in November and December 1992.

Repeated failure of the HP turbine leak-off line associated with HP turbine vibration

Three more incidents of broken leak-off lines caused another series of forced outages in July 1993. Since the unit was necessary to generate additional power to augment the brownouts in the NPC-Luzon grid, only patch repairs were made on the broken leak-off pipeline.

Following these patch repairs, the unit was re-started on 26 July 1993. During the startup, excessive vibration amplitudes were detected on bearings 1 and 2 of the HP turbine. The vibration readings obtained from a portable analyzer showed maximum amplitudes of over 381 μm (15 mil) pp, higher than the readings indicated by permanently installed instrument recorders. Because only single-plane proximity probe measurements were available in conjunction with bearing cap seismic transducers and no Keyphasor® phase reference transducer was installed, very little information could be obtained.

Editor's Note: *Bently Nevada strongly advocates the use of XY proximity probes at each radial bearing, and the installation of a Keyphasor transducer for once-per-turn timing information, when monitoring large, critical turbomachinery using fluid-film bearings.*

The seismic transducers showed little change, which is typical of machines with rigidly supported casings. While the proximity probe transducers did indicate changes from "normal" amplitudes, the inability to observe the actual shaft motion in both X and Y planes, coupled with the lack of phase information, prevented Sucat from understanding what was really happening with the machine. This lack of data, coupled with the discrepancy between the portable analyzer and the permanently installed instrument recorder, prompted a more comprehensive investigation of the problem. The goal: to determine the source of the high vibration on bearings 1 and 2 of the HP turbine and the cause of the recurring failures on the HP turbine leak-off pipeline.

Results of the investigation

An axial clearance bump test (to check the shaft's axial float) performed on the HP turbine revealed a tight 3.15 mm clearance, not the required 7.0 mm minimum clearance. The source of the recurring failures on the leak-off line was traced to a broken U-seal ring, which was seen from the peephole on the HP turbine casing. The tight axial clearance on the HP turbine was also considered a contributory factor to the multiple failures. A restart was not recommended, since the tight clearance would definitely induce rubbing between the rotating and stationary parts. The broken U-seal ring permitted the high-pressure steam to leak through into the gland steam system. The condition caused vibration and steam pulsation that could lead to cracking of the seal steam leak-off piping. After consultation with the manufacturer (Siemens), a decision was made to open the turbine on 10 August 1993 for further checks, as a preemptive measure to avoid further damage, and to replace the damaged U-seal rings.

Vibration problems after the HP turbine overhaul

The unit was placed back in operation on 23 November 1993, after the repairs were completed. However, high vibration persisted on the turbine train, with amplitude levels on bearings 1, 2, and 3 reaching 457 μm (18 mil) pp. During the event, six mounting bolts on the bearing 2 cover sheared off. A manual shutdown was initiated to prevent serious damage to the machine components. Unfortunately, the power crisis in the NPC-Luzon grid did not permit an extended shutdown for another full inspection. As mentioned previously, the lack of proper transducers and diagnostic tools prevented Sucat from acquiring valuable data, necessary to identify the source of this high vibration.

Repairs made

Work was limited to a realignment of the HP turbine and the replacement of the sheared mounting bolts on bearing 2. A complete realignment of the whole machine train, which included the generator and the exciter, was deferred, since the vibration amplitudes on these components were apparently normal before the HP turbine overhaul.

However, even after realignment, the vibration on the HP turbine remained high. A more detailed investigation was in order. To accomplish this, additional XY proximity probes

(Figure 1) were installed on bearings 1, 2, and 3 to observe the shaft vibration and position. A Keyphasor® phase reference transducer was also added at this time to permit the collection of filtered amplitude and phase data and to trigger data collection at predetermined machine speed increments. A portable data acquisition and diagnostics system, Bently Nevada's ADRE® for Windows®, was selected to collect data and information during the investigation. Data was collected during both transient (startup and shutdown) and steady-state conditions.

Developments

The unit was returned to service with its new, partial complement of vibration transducers on 9 January 1994. The vibration data collected by the ADRE for Windows system revealed extremely high shaft vibration amplitudes, reaching 330 µm (13 mil) pp on bearing 2, and 508 µm (20 mil) pp on bearing 3. A unit shutdown was initiated to collect more data for further investigation (Figures 2 and 3).

The initial question was why the high vibration persisted even after the HP turbine overhaul and realignment. A review of the vibration data from the ADRE® for Windows® system

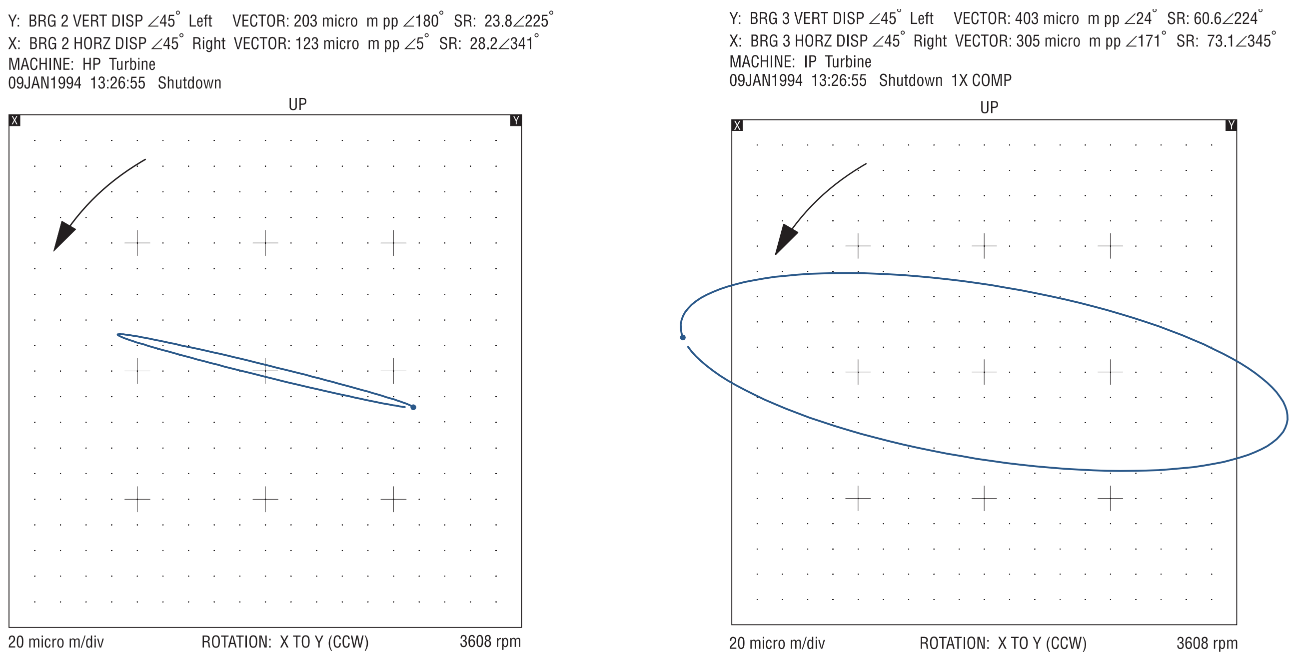

Figure 2. Shaft orbit plots at bearings 2 and 3, showing high load condition.

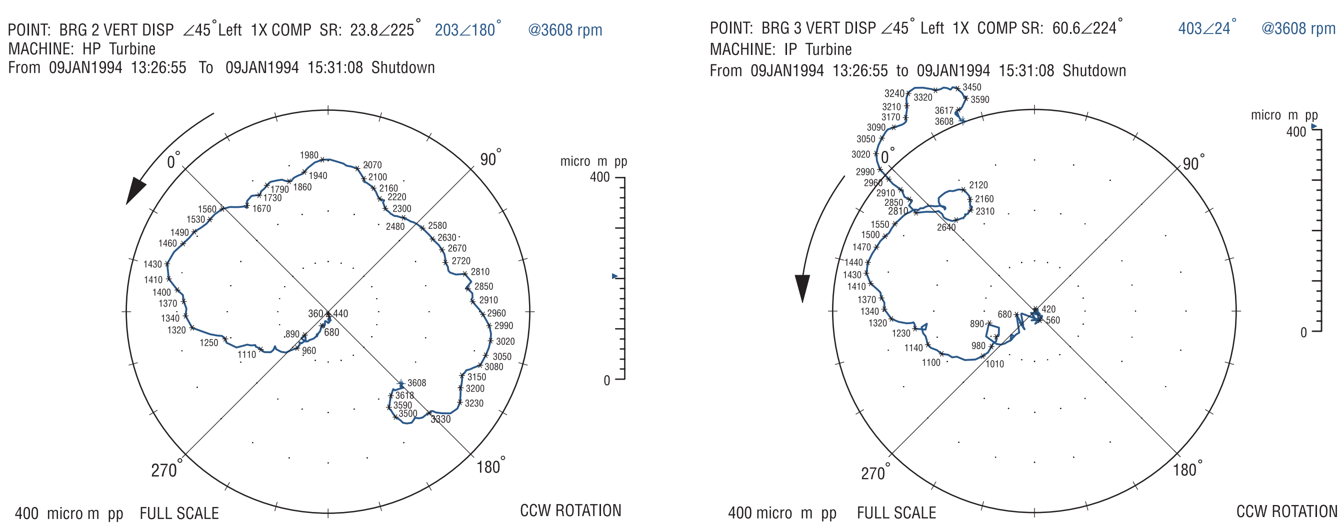

Figure 3. Polar plots at bearings 2 and 3, after realignment on 9 January 1994.

provided valuable clues: it suggested that further realignment on the HP turbine was still necessary and that unbalance was also a contributing factor. Figure 2 clearly shows the flat orbit pattern on bearing 2, indicative of a high load (in this case, the load was externally caused by misalignment between the HP and IP case). The next question was why bearing 3 (IP turbine) was now exhibiting 508 µm (20 mil) pp of radial vibration, when only the HP turbine had been overhauled. Analysis of the collected data indicated that unbalance and misalignment were mainly responsible for these high vibration amplitudes.

Attempts to correct the unbalance condition did not materialize, since the calculations showed that a 3 kg (6.6 lb) correction weight was needed! The machine was thoroughly inspected, and an end-to-end realignment was done. Fortunately, during this realignment, the real cause of this unbalance became apparent.

Findings and actions

Complete realignment requires uncoupling the shafts and removing the turning gear (located between the IP and LP cases) to verify the axial alignment. When the turning gear was removed, a plug, that should normally reside in the end of the IP shaft, was discovered in the much bigger inner diameter of the turning gear (Figure 4). The plug on the hollow IP turbine shaft allows major inspection for ultrasonic testing. It was determined that the detached plug was the main cause of the excessive unbalance on bearing 3, caused by the tremendous dynamic force created during operation.

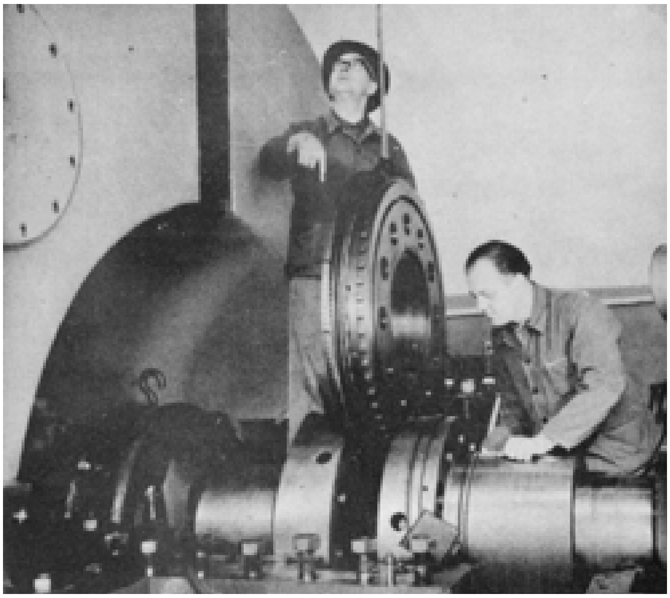

Figure 4. Detached IP shaft plug was found resting on inner diameter of the turning gear.

The 15.5 kg (34 lb) plug measures 60 mm (2.4 in) thick by 210 mm (8.3 in) diameter.

Actions

The usefulness of the data provided by the XY probes at bearings 1 through 3 prompted plant personnel to add additional XY proximity probes on the remaining bearings (bearings 4 through 9). These additional probes provided immediate value in identifying residual unbalance elsewhere on the machine.

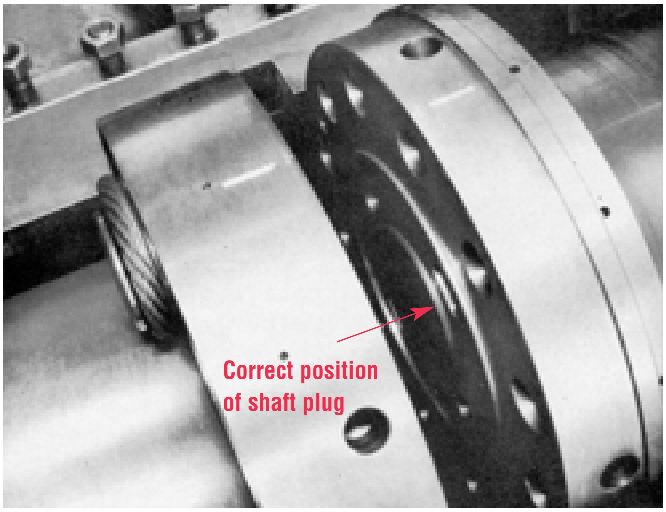

Figure 5. Plug properly installed in IP shaft.

Machine behavior after test and inspection

The plug was returned to its correct location in the IP shaft (Figure 5), and the unit was placed back online following realignment. The vibration response during load changes was observed and recorded. The ADRE® for Windows® system indicated vibration amplitudes at bearing 3 were at normal levels. Bearings 2 and 9, however, exhibited high 1X vibration, and examination of the data indicated this was from an unbalance. A field balance was scheduled to reduce the vibration amplitudes at these bearings. The data collected during transient and steady-state conditions was used to determine the amount and locations of the correction weights. The correction was carried out simultaneously on bearings 2 and 9, since no cross-effect from each correction weight was expected.

The initial correction weights reduced the 1X vibration amplitudes, as seen in the polar plot responses from the horizontal probes at bearings 2 and 9, respectively (Figure 6). The next field balancing attempt, made by repositioning the correction weights, was successful in reducing the vibration on bearings 2 and 9 even more. The unit was placed back

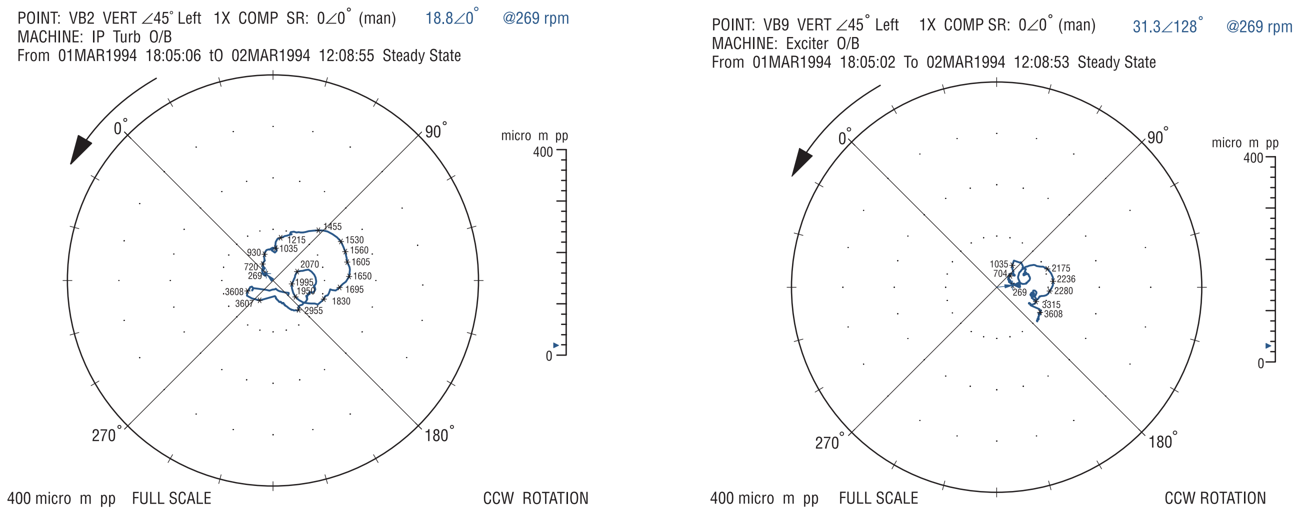

Figure 6. Polar plots of response at bearings 2 and 9 during startup after the initial balance correction.

online on 2 March 1994, with normal and acceptable vibration levels (Table 2).

Conclusion

The correct complement of transducers, coupled with a capable data acquisition and diagnostic system, helped Sucat progress from limited data and the subsequent need for manual inspection and forced outages, to a more proactive approach. For critical turbomachinery with fluid-film bearings, XY proximity probes at each radial bearing location are the correct choice. The need for a Keyphasor® transducer, to provide once-per-turn timing information for phase measurements and filtered vibration readings, is critical as well. Once proper data was available, machine conditions could be analyzed and corrective measures planned and carried out more efficiently.

The turbine generator sets are the most critical equipment in the power station and are operated at high speed, high pressure, and high temperature. Now that they have the proper complement of transducers installed, Sucat has upgraded to a more reliable and modern machinery protection system and continuous machinery management system. Their initial experience with ADRE for Windows, Bently Nevada's portable data acquisition system, convinced them of the value such a system offers and expedited their decision to upgrade to Bently Nevada's continuous online software and permanent machinery protection systems.

Transducer ID	Vibration amplitude before balancing µm (mil) pp	Vibration amplitude after balancing µm (mil) pp
2V	108 (4.25)	17.0 (0.67)
2H	133 (5.24)	16.0 (0.63)
9V	122 (4.80)	75.7 (2.98)
9H	237 (9.33)	61.0 (2.40)

Table 2. 1X response at bearings 2 and 9, before and after final correction.